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REFLECTANCE SPECTROSCOPY AND MINERALOGY OF PRIMITIVE ACHONDRITES-LODRANITES

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Abstract: Reflectance spectra of three mineralogically characterized primitive achondrites have been measured for the first time and are compared with that of 29 Amphitrite to gain better understanding of the origin of the S-type asteroids. Those achondrites can be arranged in order of increasing degree of reduction from chondrites as follows: Acapulco-type winonaites Allan Hills (ALH)-78230 and ALH-77081, lodranite Yamato (Y)-791491, and a partly reduced lodranite Y-74357. A proposed pairing of Y-791491 with Y-791493 has been supported by our mineralogical characterization. Olivine crystals in Y-74357, which is similar to carbon-free ureilite, have many fractures decorated by troilite, and Mg/(Fe+Mg) ratio more reduced than that of the coexisting pyroxene. As a result of simulations of the reflectance spectrum of Amphitrite by those of the primitive achondrites and an iron meteorite, we suggest that a primitive achondrite more reduced than Y-74357 can reproduce the S-type spectrum.

1. Introduction

Visible and near-infrared reflectance spectroscopy is the most sensitive technique presently to constrain asteroid surface mineralogy. Comparison of the surface mineralogy of asteroids and meteorite mineralogy has shown that an asteroid with chondritic mineral assemblage is virtually absent in the main belt asteroids (*e.g.*, MCFADDEN *et al.*, 1985). If this statement is true, it would mean that the most common meteorites classes are not abundant in the region, from which the most meteorites are believed to be derived, or that parent asteroids have been modified since the formation of asteroids.

The S-type asteroids are the most common, dominating the inner belt population, but their compositions and thermal histories are the most strongly debated (GAFFEY *et al.*, 1989, 1990). BELL *et al.* (1985) and HIROI and TAKEDA (1990) proposed that some of the S-type asteroids are related to a group of meteorites called primitive achondrites.

Primitive achondrite is the group name suggested for all of the ungrouped meteorites and clasts that have mineralogy similar to chondrites but contain no chondrules (PRINZ *et al.*, 1983). The members of this group include winonaites, Acapulco-type chondrites, forsterite chondrites, lodranites, brachina, silicate inclusions in IAB and IIICD irons. KALLEMEYN and WASSON (1985) recommended cessation of the usage

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of the terms forsterite chondrite or winonaite. Winona is a rusted unrepresentative meteorite to be used as a meteorite class (MASON, private communication, 1983).

Despite their significance to the origin of meteorites and asteroids, no reflectance spectra of primitive achondrites have been measured up to date. Yamato (Y)-791493 was classified as the second lodranite (YANAI and KOJIMA, 1982) and Y-791491 was proposed to be a paired piece of Y-791493 (MASON, private communication, 1983). Y-74357 and Y-75274, which are related to lodranite, have been studied by YANAI *et al.* (1984) and MORI *et al.* (1984) and classified as primitive achondrites. Petrology of Y-791493 has been reported in detail by NAGAHARA and OZAWA (1986).

In this paper, we report the first measurement of the reflectance spectra of primitive achondrites Y-791491 and Y-74357 together with Allan Hills (ALH)-77081, which was previously characterized by TAKEDA *et al.* (1980). Mineralogical studies of Y-791491 and Y-74357 have been performed to characterize the specimens used for the spectroscopic measurements. We support the previous proposal that Y-791493 and Y-791491 are paired specimens. ALH-78230 and Y-74357 were studied as a part of the consortium studies of unique meteorites from Antarctica (NAGAHARA *et al.*, 1990).

2. Samples and Experimental Methods

Small chips of Y-791491 and Y-74357, each of which has a nearly flat and fresh surface, were loaned from the National Institute of Polar Research (NIPR) for this measurement for a few days. A flat chip of ALH-77081 with one side fresh and the other side rusty surface, which was removed from the specimen for other previous studies, was used for this measurement. A chip of extensively recrystallized H6 chondrite Y-82111, was also studied for comparison.

An iron meteorite Mundrabilla was cut to have a large (about 2 cm$\times$3 cm) fresh surface. Its surface was polished by diamond paste and then by sand papers to create diffuse reflection which we believe to occur on the surface of metallic asteroid. The reflectance spectra of the freshest surfaces of chips of Y-82111, ALH-77081, Y-791491, and Y-74357 were measured.

All the reflectance spectra of the above samples were measured with a Beckman UV5240 UV-Vis-NIR spectrophotometer equipped with an integrating sphere, at the Department of Pure and Applied Sciences, College of Arts and Sciences, University of Tokyo. The incident light was perpendicular to each sample surface, and its integrated reflectance was measured at every 0.5 nm from 250 to 2550 nm in wavelength. Halon was used as the standard reference material. A photomultiplier was used from 250 to 800 nm in wavelength, and a PbS cell detector from 800 to 2550 nm. Those two detectors were installed on the top and bottom of the inside surface of the integrating sphere.

The chemical compositions of minerals in the polished thin sections (PTS) of Y-82111, ALH-77081, ALH-78230, Y-791491, and Y-74357 were measured with JEOL JXA-733 electron microprobe at the Ocean Research Institute, University of Tokyo. The correction procedures were based on Bence-Albee method with the same parameters used by NAKAMURA and KUSHIRO (1970). Back-scattered electron images (BEI) and chemical map analysis (CMA) for 15 elements have been employed to obtain mineral distribution maps of the PTS's on JEOL 840A SEM equipped with EDS and Kevex Super 8000 units. A PTS of Lodran from American Museum of Natural History, was also studied for comparison, by one of the authors (H. T.).

3. Results

3.1. Mineralogy of Y-791491

Physical description of Y-791491 lodranite is given by YANAI and KOJIMA (1987). PTS Y-791491,61–2 we investigated shows a coarse-grained aggregate with granular textures and consists mainly of olivine, orthopyroxene (opx), and nickel-iron with minor augite, plagioclase, troilite, Cl-apatite, and whitlockite (Fig. 1a). Modal analyses by the BEI-CMA methods give 41.9 (vol) % olivine, 28.0% opx, 0.07% augite, 29.5% nickel-iron-troilite, 0.25% plagioclase, and traces of Ca phosphates (0.15%), chromite (0.1%), and other phases (Fig. 2). The olivine and pyroxene crystals are present as euhedral to subhedral grains up to 1 mm in size. Small rounded grains of opx and chromite up to 0.1 mm are poikilitically included in olivine and vise versa. Nickel-iron, plagioclase, and augite fill the interstices of mafic silicates and often show concave, rounded boundaries. Orthopyroxene crystals show linear cracks along the *c* axis. Olivine crystal has cracks, but some crystals show crack-free area for about one half of the crystal. The textures and mineral distribution are the same as those described by NAGAHARA and OZAWA (1986).

Chemical compositions of olivine is uniform (Table 1) throughout the PTS, and Fo values range from 92 to 87 (Fig. 3). At the rims of some crystals, reverse zoning (Mg-rich towards outside) were detected. MnO contents range from 0.38 to 0.54 wt% and are identical to those of Y-791493 (NAGAHARA and OZAWA, 1986). CaO contents are low in comparison with those of ureilites.

Chemical compositions of opx are roughly uniform for major elements (Table 2), but CaO contents are strongly zoned within a crystal. CaO contents of outer 30 μm of a crystal gradually decrease from the core (0.23 wt%) to the rims (0.12 wt%). This trend is similar to that observed in Lodran, which contains variable amounts of fine exsolved lamellae of augite on (100) and at the rims augite lamellae are absent. Minor augite crystals contain high Na_2O and Cr_2O_3, which are consistent with those of other primitive achondrites (Fig. 4). The chromite compositions are given in Table 3.

Plagioclase occurs as a film mantling a olivine crystal and fills interstices of olivine and opx together with whitlockite, metal, and augite. Twin lamellae are present. The chemical compositions of plagioclase ($An_{18.5}$ to $An_{16.3}$) are given in Table 4. The An content is the same as that of Y-791493 (NAGAHARA and OZAWA, 1986). The locations of augite and plagioclase were searched by the CMA of Si, Al, and Ca X-ray radiations.

3.2. Mineralogy of Y-74357

A PTS Y-74357,62-1 was examined as a part of the consortium study. The detailed description of neighboring PTS (,62-2) has been given by YANAI and KOJIMA a.

b.

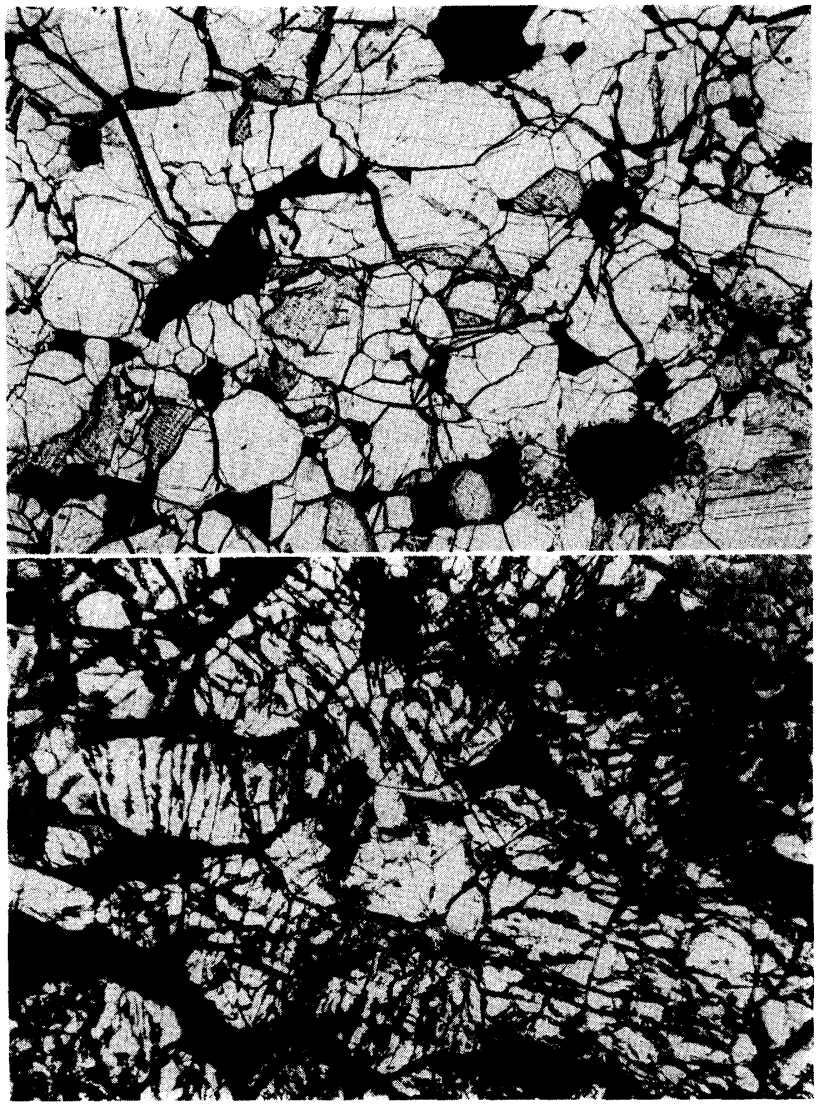
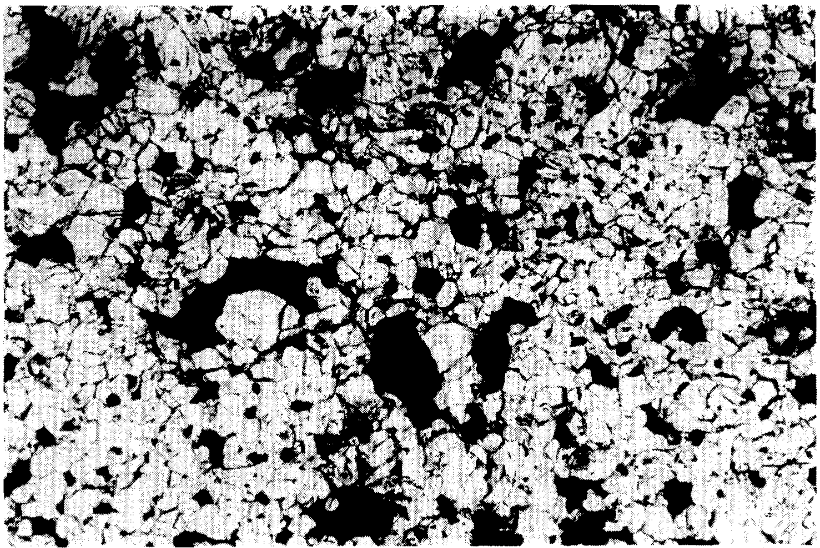


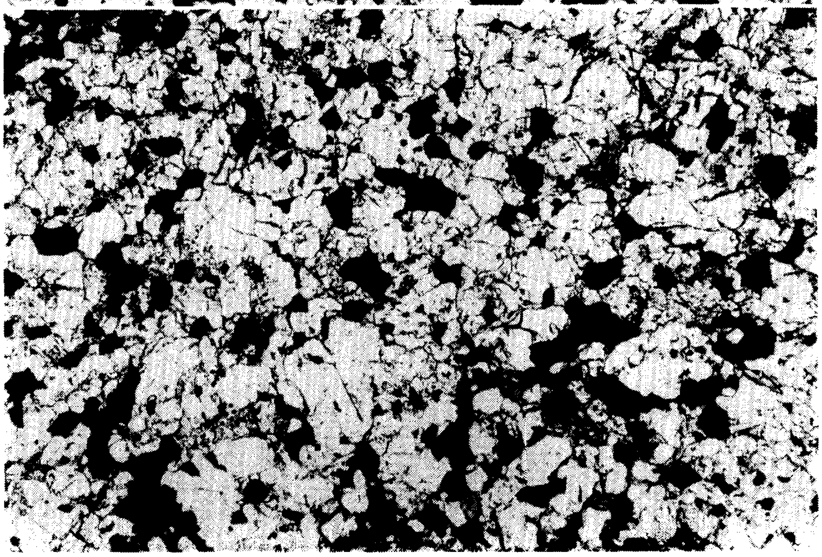
Fig. 1. Photomicrographs of (a) Y-791491, (b) Y-74357,

(1987). The characteristic features of the new PTS (Fig. 1b) are identical with the old one (,62-2). An apparent overall feature of this lodranite is similar to that of ureilites, except for the absence of carbonaceous veins and presence of nickel-iron. It can be described in a textural sense as a carbon-free, metal-rich ureilite. The section shows a coarse-grained granular aggregate of mafic silicates and consists mainly of olivine and smaller amount of opx, augite, and metal. One characteristic of this lodranite related to spectroscopic properties is fine fractures in euhedral olivine up to 1.5 mm across decorated by mainly troilites. Metal appears to fill the interstices of mafic silicate crystals. Metal, opx, and augite are somewhat aligned along a certain orientation.

Modal abundance of each minerals obtained by the CMA method is 83% olivine, 6% opx, 3% augite, 8% metal, and traces of chromite and troilite (Fig. 2). In spite of extensive search for plagioclase, we could not find it except for one analysis An_{15} $Ab_{82}Or_3$.



c.



d.

(*c*) *ALH-78230*, (*d*) *Y-82111*. *Width is 3.3 mm.*

Chemical compositions of olivine and opx (Fig. 3) are not equilibrated pair. Olivine $Fa_{7.9}$ is more Mg-rich than opx $Fs_{13.8}$. Slight chemical zoning detected at the rims of opx suggests that this olivine was completely reduced during a subsolidus annealing episode, because of higher diffusion rate of Fe in olivine than in opx.

3.3. *Mineralogy of ALH-78230 and ALH-77081*

Although we measured the spectra of ALH-77081, the mineralogical description is not given in detail in this paper, because this Acapulco-type meteorite (PALME *et al.*, 1981) has been previously studied (TAKEDA *et al.*, 1980). Instead, we will describe ALH-78230, 51-2, which is similar to ALH-77081 (YANAI and KOJIMA, 1987).

The olivine and opx up to 0.6 mm in diameter poikilitically enclose one another and sometimes plagioclase, augite, metal, and troilite (Fig. 1c). Plagioclase, augite, and chlorapatite often occur at interstices of major minerals. Metal grains up to 0.3 mm along the longest dimensions have complex shapes with concave rounded

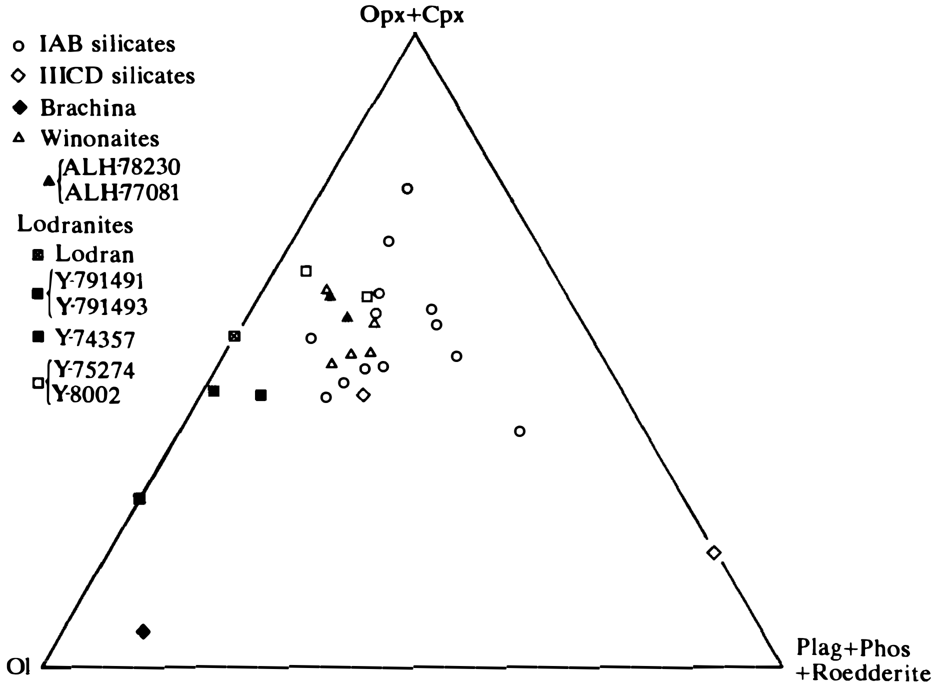


Fig. 2. Modal abundances of primitive achondrites plotted in a diagram by PRINZ et al. (1983).

Table 1. Chemical compositions of olivines in Y-791491/3 and Lodran.

	Lodran	Y-791491 core	Y-791493* Ol (1)
(wt%)			
SiO_2	39.0	39.5	39.7
TiO_2	0.04	0.02	0.00
Al_2O_3	0.02	—	0.08
FeO	14.00	12.28	12.0
MnO	0.54	0.46	0.58
MgO	45.4	47.1	46.7
CaO	0.05	0.02	0.00
Na_2O	0.02	—	0.00
Cr_2O_3	0.03	0.05	0.00
Total	99.04	99.43	99.1
(Cations) O=4			
Si	0.988	0.987	0.995
Ti	0.001	0.000	0.000
Al	0.001	—	0.002
Fe	0.296	0.257	0.251
Mn	0.012	0.010	0.012
Mg	1.710	1.754	1.744
Ca	0.001	0.001	0.000
Na	0.001	—	0.000
Cr	0.001	0.001	0.000
Total	3.011	3.010	3.004
Mg/(Mg+Fe)**	0.852	0.872	0.874
Fo	85.2	87.2	87.4
Fa	14.8	12.8	12.6

* Data from NAGAHARA and OZAWA (1986).

** Atomic ratio.

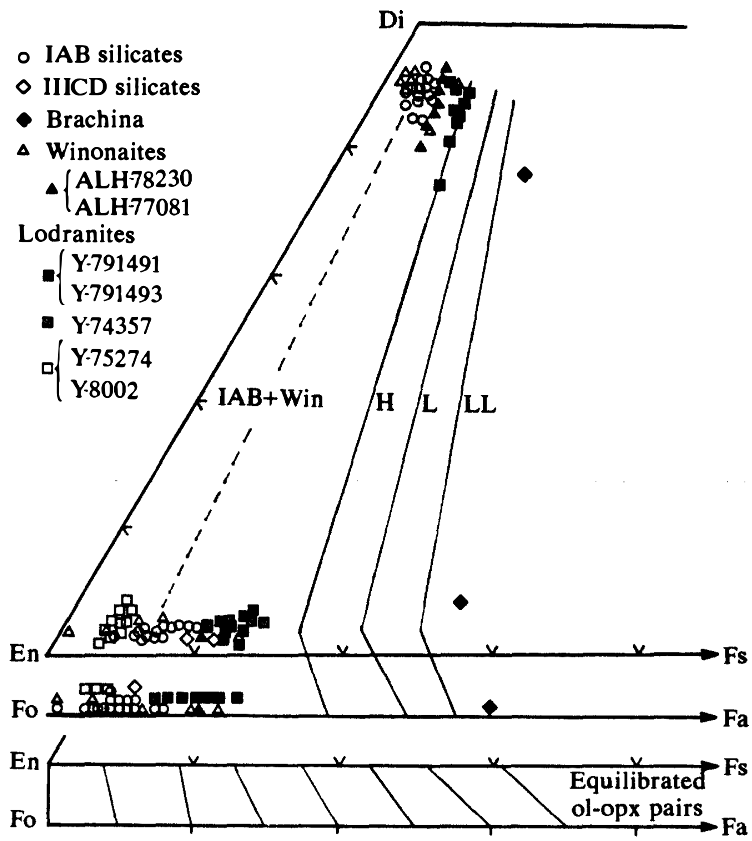


Fig. 3. Chemical compositions of pyroxenes and olivines in primitive achondrites plotted in a diagram by PRINZ *et al. (1983).*

boundaries and appear to fill interstices of major mafic silicates.

Modal analyses of ALH-78230 by the CMA method give 44% opx, 25% olivine, 7% plagioclase, 21% metal-troilite, 3% augite, and less than 1% Ca phosphates. Our new measurement of ALH-77081 is: 57% opx, 16% olivine, 12% plagioclase, 9% metal-troilite, and 5% augite.

The compositions of the olivine (Fa_{10}) and opx ($Ca_1Mg_{89}Fe_{10}$) are uniform and are intermediate between E and H chondrites (Fig. 3). The composition of plagioclase ranges from $An_{13.5}$ to $An_{15.0}$. All silicate mineral grains do not show fractures.

Medium-grained mineral texture, their chemistries, and modal abundances of minerals show that ALH-78230 is rather similar to ALH-77081, which is an Acapulco-type primitive achondrite. Therefore, spectral characteristics of ALH-77081 can be interpreted in terms of this type. The ALH-77081 spectrum shows rather deep absorptions of opx and olivine and is not much different from those of well-recrystallized H chondrites as will be shown later (Figs. 5 and 6).

3.4. *Mineralogy of Y-82111 chondrite*

This chondrite (H6) is one of the possible paired specimens found in the Yamato collection. This group includes Y-82161 and Y-82163 (YANAI and KOJIMA, 1987). PTS Y-82111,61-2 shows a well-crystallized texture of opx (35%), olivine (35%),

Table 2. Chemical compositions of pyroxenes in Y-791491/3 and Lodran.

Meteorites Phase	Lodran Opx	Lodran Aug	Y-791491 Opx	Y-791491 Aug	Y-791493* Opx
(wt%)					
SiO_2	56.1	54.5	56.4	54.1	56.5
TiO_2	0.24	0.55	0.15	0.45	0.23
Al_2O_3	0.50	1.03	0.46	1.01	0.49
FeO	8.75	6.47	7.97	3.27	7.78
MnO	0.59	0.36	0.48	0.23	0.57
MgO	31.4	17.56	32.5	17.78	31.8
CaO	1.80	21.1	1.37	21.3	1.57
Na_2O	0.07	0.75	0.05	0.80	0.04
Cr_2O_3	0.53	1.39	0.39	1.20	0.47
Total	99.98	100.71	99.77	100.14	99.45
(Cations) O=6					
Si	1.971	1.968	1.973	1.963	1.984
Ti	0.006	0.015	0.004	0.012	0.006
Al	0.021	0.044	0.019	0.043	0.020
Fe	0.257	0.105	0.233	0.099	0.228
Mn	0.018	0.011	0.014	0.007	0.017
Mg	1.645	0.945	1.697	0.963	1.665
Ca	0.068	0.815	0.051	0.829	0.059
Na	0.005	0.053	0.004	0.057	0.003
Cr	0.015	0.041	0.011	0.034	0.013
Total	4.006	3.997	4.006	4.007	3.995
Mg/(Mg+Fe)**	0.865	0.900	0.879	0.907	0.879
En	83.5	50.7	85.6	50.9	85.3
Fs	13.1	5.6	11.8	5.2	11.7
Wo	3.4	43.7	2.6	43.9	3.0

* Data from NAGAHARA and OZAWA (1986).
** Atomic ratio.

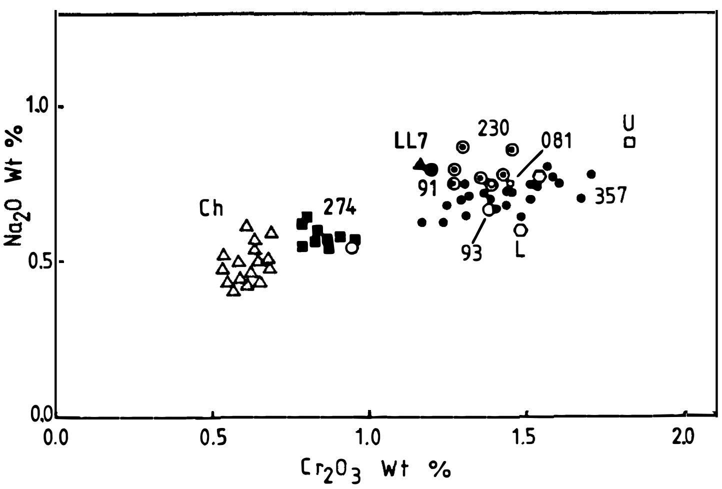


Fig. 4. Na_2O versus Cr_2O_3 plot of augite in primitive achondrites and strongly recrystallized chondrites. Ch: type 6 ordinary chondrites, LL7: Y-74160, L: Lodran, U: ureilite Y-74130, 91: Y-791491, 93: Y-791493, 274: Y-75274, 081: ALH-77081, 230: ALH-78230 and 357: Y-74357 are given.

Table 3. Chemical compositions of spinels (chromites) in Y-791491/3.

	Y-791491		Y-791493*
(wt%)			
Al_2O_3	4.97	8.13	5.98
TiO_2	0.60	0.71	0.66
FeO	23.8	23.7	23.9
MnO	0.87	0.93	1.36
MgO	5.28	5.42	4.82
Cr_2O_3	64.3	60.4	61.9
V_2O_3	0.51	0.44	0.66
ZnO	—	—	0.80
Total	100.43	99.79	100.1
(Cations) O=4			
Al	0.203	0.330	0.246
Ti	0.015	0.018	0.017
Fe	0.692	0.680	0.697
Mn	0.026	0.027	0.040
Mg	0.273	0.278	0.251
Cr	1.765	1.643	1.707
V	0.014	0.012	0.019
Zn	—	—	0.021
Total	2.994	2.991	2.997
Mg/(Mg+Fe)**	0.283	0.290	0.264
Cr/(Cr+Al)**	0.897	0.833	0.874

* Data from NAGAHARA and OZAWA (1986).
** Atomic ratio.

Table 4. Representative chemical compositions of plagioclases in Y-791491/3.

	Y-791491		Y-791493*
(wt%)			
SiO_2	63.4	63.6	64.9
TiO_2	0.01	0.04	0.00
Al_2O_3	23.3	22.6	22.7
FeO	0.11	0.04	0.09
MgO	0.03	0.03	0.00
CaO	4.09	3.78	4.05
Na_2O	9.67	9.54	9.31
K_2O	0.18	0.31	0.47
Total	100.89	99.9	101.5
(Cations) O=8			
Si	2.786	2.814	2.827
Ti	0.000	0.001	0.000
Al	1.205	1.177	1.165
Fe	0.004	0.001	0.003
Mg	0.002	0.002	0.000
Ca	0.192	0.179	0.189
Na	0.824	0.818	0.786
K	0.010	0.018	0.026
Total	5.026	5.014	4.996
An	18.7	17.7	18.9
Ab	80.3	80.6	78.5
Or	1.0	1.7	2.6

* Data from NAGAHARA and OZAWA (1986).

nickel-iron-troilite (24%), plagioclase (5%), and minor augite (1%). This medium-grained equigranular texture is similar to the Acapulco-type primitive achondrites and Y-74160 (LL7) chondrite (Fig. 1d), but there were not found prominent crystal growth textures from a melt pocket as was observed in Y-74160, and still recognizable remnants of broken chondrules have been observed rarely. Intergranular distribution of nickel-iron-troilite and plagioclase is similar to those of ALH-78230 (Fig. 1c).

Orthopyroxene up to 0.5 mm in diameter poikilitically encloses small rounded olivine crystals. Plagioclase, augite, and whitlockite often occur at the interstices of major minerals. The orthopyroxene and olivine crystals show more fractures than ALH-78230, and the metal contents are smaller than those of ALH-78230 and their grain shapes not as rounded as those of ALH-78230. These observations show no indication of large-scale melting and reduction.

3.5. Spectral comparison between the S-type asteroids and primitive achondrites

Reflectance spectra of three primitive achondrites are shown in Fig. 5. To demonstrate spectral characteristics of the primitive achondrites and the S-type asteroids, we compare the reflectance spectrum of an S-type asteroid 29 Amphitrite (BELL *et al.*, 1985) with those of an H6 chondrite Y-82111 and an iron meteorite Mundrabilla (HIROI and TAKEDA, 1989b, 1990) in Fig. 6.

Reflectance spectra of Amphitrite, Y-82111, and the primitive achondrites have the common characteristic absorption bands assigned to Fe^{2+} ions in olivine, opx, augite, and plagioclase (HIROI *et al.*, 1985a). As the silicate grains in those primitive achondrites become more reduced, their absorption bands become shallower. Amphitrite spectrum has also reddened profile which suggests the existence of iron-nickel such as Mundrabilla.

In general, any absorption band in reflectance spectra of powders becomes shal-

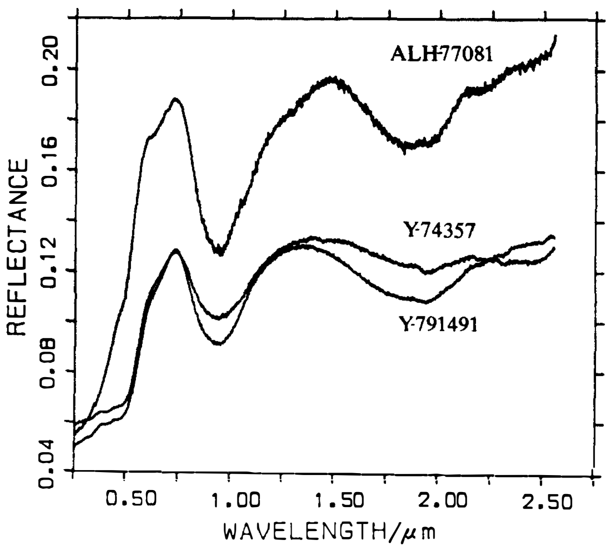


Fig. 5. Reflectance spectra of primitive achondrites: an Acapulco-type (winonaite) ALH-77081, a lodrantie Y-791491, and a partly reduced lodranite Y-74357.

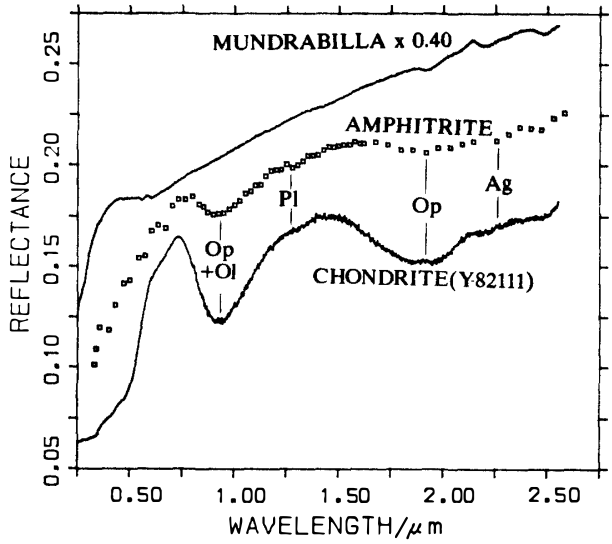


*Fig. 6. Reflectance spectrum of an asteroid 29 Amphitrite (*Bell *et al., 1985) compared with those of an H6 chondrite Y-82111 and an iron meteorite Mundrabilla.*

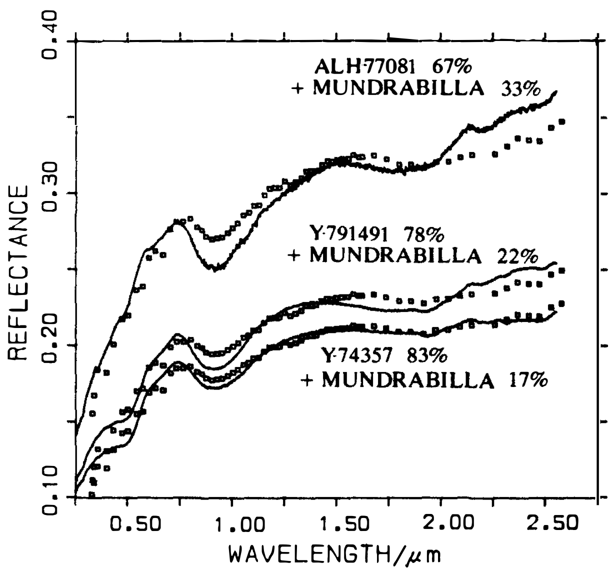


Fig. 7. Least square fittings of reflectance spectrum of Amphitrite by those of primitive achondrites and Mundrabilla.

lower as their grain sizes or Fe^{2+} contents become smaller (Hiroi *et al.*, 1985b; Hiroi and Takeda, 1989a), But grinding a chondrite into fine powder and increasing its iron-nickel content are still insufficient to explain the spectral feature of Amphitrite in visible range (Hiroi and Takeda, 1989b, 1990), and the required grain size of the chondrite is too small (several microns) to be realistic.

Therefore, we tried to simulate the S-type spectrum by reduction and increase of nickel-iron, employing the spectra of primitive achondrites (instead of chondrites) and Mundrabilla. We assumed a regional (linear) mixing between each primitive achondrite and Mundrabilla, because making an ideal mixture between silicates and metal powder is very difficult due to unusual (thin) shapes of ground metal grains. The linear combination coefficients and the absolute scale of Amphitrite spectrum were optimized by least-square method.

The results are shown in Fig. 7. As the reduction of the primitive achondrite increases, the fitting is improved and the amount of Mundrabilla becomes smaller. We expect that another primitive achondrite which is more reduced than Y-74357 can reproduce the Amphitrite spectrum better by mixing less iron-nickel than any other primitive achondrites.

4. Discussion

4.1. Mineralogical characterization of new primitive achondrites

Some primitive achondrites studied in this paper except for Y-791491 lodranite and Y-82111 chondrite have been studied as a part of the Unique Meteorites Consortium Study (NAGAHARA *et al.*, 1990). We will not discuss much about the consortium samples in this paper, but some mineralogical features directly related to their spectral properties will be discussed.

The texture of Y-74357 is particularly interesting, because its apparent texture at a glance is similar to that of some ureilites (TAKEDA, 1989), except for that troilite veins and oxydized iron minerals are abundant in Y-74357 in stead of carbon in ureilite. Since a formation model for primitive achondrites proposed by us (TAKEDA and HIROI, 1990) is based on a planetesimal-scale collision model proposed for ureilites (TAKEDA, 1989), it is not surprising to have a similar texture. Similarity between Lodran and ureilites has been also pointed out by BILD and WASSON (1976), and both contain high planetary type noble gases, and olivine rims are partly reduced.

TAKEDA and HIROI (1990) suggested that the presence of volatiles in the source carbonaceous materials of ureilites will make large difference in removing Ca-Al partial melts and residuals of crystal growth and Fe-Ni-S eutectic melts in the case of ureilites. Because primitive achondrites still preserve such materials, it should be easy to trace down the formation process of the primitive achondrites.

Another characteristic of Y-74357 is that olivine crystals have many small fractures decorated by troilites and that Mg/(Mg+Fe) ratio of olivine is more reduced than coexisting pyroxene (Fig. 3). These fractures reduce the grain size of olivine and also reduce the absorption band strength of olivine. This phenomenon can be interpreted by the following process: By shock, fractures of tilt boundaries (MORI and TAKEDA, 1983) had been produced in olivine crystals, and then they were annealed at temperature, where Fe-Mg diffusion in olivine took place, but not in pyroxenes. This difference in Fe-Mg distribution is possible because of slower diffusion of Fe-Mg in pyroxene than in olivine.

Y-791491 was proposed to be a paired piece of Y-791493 (MASON, private communication, 1983), which was described by NAGAHARA and OZAWA (1986). Considering the very coarse-grained textures of Y-791491 and Y-791493, we have no mineralogical data against the proposed pairing. Especially, the presence of plagioclase in Y-791491 similar to that in Y-791493, similar chemistries of both minerals, and their modal abundances are in favor of their pairing.

Medium-grained textures (Fig. 1) and mode of mineral distribution of ALH-77081, ALH-78230, and Y-82111 are rather similar to each other, in spite of their differences in the meteorite classification. This observation indicates that spectral characteristics of ALH-77081 can be interpreted in terms of mineral assemblage of ALH-78230 described in this paper. Because their differences are mainly in their amounts of Ca-Al-containing minerals and of nickel-iron and troilite and in their oxidation reduction condition, their formation processes may be similar.

4.2. Searching the best candidates for the S-type asteroids

Amphitrite is one of the S-type asteroids whose reflectance spectra have been measured for the widest range of wavelength, and many other S-type asteroids have similar spectra to that of Amphitrite, but with certain variations (GAFFEY *et al.*, 1990). Our result suggests that a highly reduced lodranite may be a good candidate for the S-type asteroids.

We have shown the modal abundances of the primitive achondrites in Fig. 2, and the chemical compositions of their pyroxenes and olivines in Fig. 3, plotted in the diagrams after PRINZ *et al.* (1983). Lodranites (indicated by squares) can be divided into three types: ordinary (Y-791491 and Y-791493), partly reduced (Y-74357), and reduced (Y-75274 and Y-8002). This division is not definite one, but a series of different degrees of reduction may be possible.

Among our meteorite collection plotted in Figs. 2 and 3, the best candidates for the S-type asteroids are reduced lodranites (Y-75274 and Y-8002) and some other highly reduced winonaites (indicated by triangles). Spectral reflectances of those lodranites and winonaites have not yet been measured mainly because of their very small amount. However, we should measure every type of important meteorites for the study of the origin of asteroids.

In recent two decades, the similarities on reflectance spectra between asteroids and meteorites were pointed out by many investigators (*e. g.*, MCFADDEN *et al.*, 1985). None of those studies, however, have solved the problem that there is no main belt asteroid which has the same reflectance spectrum as chondrites. It is a very important subject whether the most popular meteoritic materials (chondrites) are also the most popular in the main belt.

In our separate paper (HIROI and TAKEDA, 1990; TAKEDA and HIROI, 1990), we have shown that the S-type spectrum can be interpreted on the basis of modified chondrites, and that the S-type asteroids, which are very popular in the main belt, may also have the same origin as chondrites. Origin of the S-type asteroids with primitive achondrite affinity could be explained on the basis of a planetesimal-scale collision model proposed for ureilites (TAKEDA, 1989; TAKEDA and HIROI, 1990).

GAFFEY (1984) says that asteroid 8 Flora may be a residual core of a thermally evolved, magmatically differentiated, and collisionally disrupted planetesimal. Our result that the S-type asteroids may have the regional mixtures between reduced primitive achondrites and nickel-iron metal, is also consistent with his suggestion, because the core may be a mixture between thermally modified materials and abundant nickel-iron metal, if his spectral interpretation is valid.

5. Summary

(1) Reflectance spectra of lodranite and Acapulco-type chondrite have been measured for the first time.

(2) Mineralogy of Y-791491 indicates that it is very similar to Y-791493 previously described as a lodranite, and that they are paired.

(3) Y-74357 mainly consists of olivine, which are more reduced than the coexisting pyroxenes.

(4) Y-74357 olivine crystals show abundant fractures decorated by fine troilites.

(5) ALH-78230 is mineralogically similar to ALH-77081, which is similar to Acapulco-type chondrites.

(6) Y-82111 is an H6 chondrites, but its texture is very similar to that of ALH-78230, indicating their similar formation mechanism.

(7) Reflectance spectra of the S-type asteroids can be well simulated by a more reduced lodranite, than those for which spectral reflectances have been measured to date.

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